US010375097B2

(12) **United States Patent**
Kopp et al.

(10) **Patent No.: US 10,375,097 B2**
(45) **Date of Patent: Aug. 6, 2019**

(54) **IDENTIFYING SELF-SIGNED CERTIFICATES USING HTTP ACCESS LOGS FOR MALWARE DETECTION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 191 days.

(21) Appl. No.: **15/386,006**

(22) Filed: **Dec. 21, 2016**

(65) **Prior Publication Data**

US 2018/0176240 A1 Jun. 21, 2018

(51) **Int. Cl.**
H04L 29/06 (2006.01)
H04L 9/32 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 63/1425*** (2013.01); ***H04L 9/3263*** (2013.01); ***H04L 63/0428*** (2013.01); ***H04L 63/0823*** (2013.01); ***H04L 63/145*** (2013.01); ***H04L 63/1416*** (2013.01); ***H04L 63/166*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 63/1425; H04L 63/0428; H04L 63/0823; H04L 63/1416; H04L 63/145; H04L 63/166; H04L 9/3263
See application file for complete search history.

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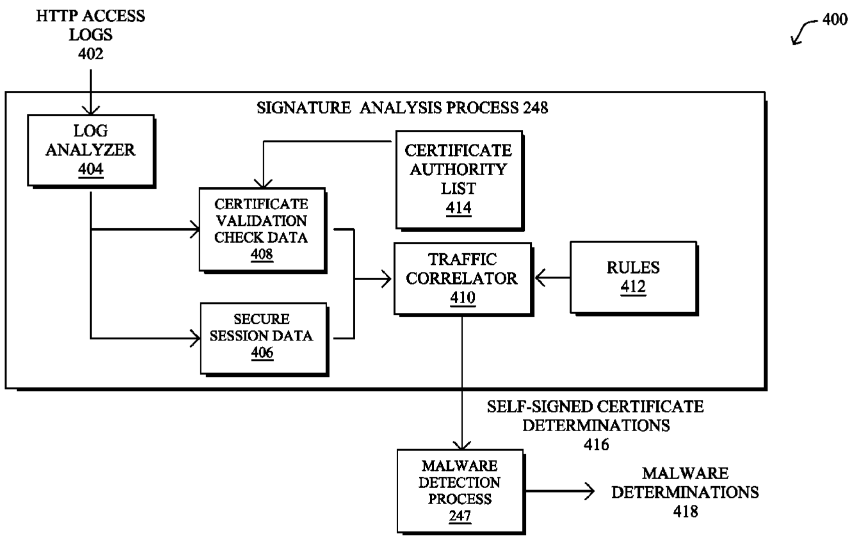
(57) **ABSTRACT**

In one embodiment, a device in a network receives traffic information regarding one or more secure sessions in the network. The device associates the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information. The device makes a self-signed certificate determination for an endpoint domain of a particular secure session based on whether the particular secure session is associated with certificate validation check traffic. The device causes the self-signed certificate determination for the endpoint domain to be used as input to a malware detector.

17 Claims, 8 Drawing Sheets


400
HTTP ACCESS LOGS 402
SIGNATURE ANALYSIS PROCESS 248
LOG ANALYZER 404
CERTIFICATE VALIDATION CHECK DATA 408
CERTIFICATE AUTHORITY LIST 414
TRAFFIC CORRELATOR 410
RULES 412
SECURE SESSION DATA 406
SELF-SIGNED CERTIFICATE DETERMINATIONS 416
MALWARE DETECTION PROCESS 247
MALWARE DETERMINATIONS 418

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https://en.wikipedia.org/wiki/Online_Certificate_Status_Protocol; Wikipedia; Online Certificate Status Protocol; pp. 1-4.
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Blake Anderson et al.: "Deciphering Malware's Use of TLS (without Decryption)", arxiv.org, Cornell University Library, 201 Olin Library, Cornell University, Ithaca, NY 14853, Jul. 6, 2016.
Ietf: "RFC 5280—Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", May 1, 2008, Retrieved from the Internet: URL:https://tools.ietf.org/html/rfc5280 [retrieved on Aug. 25, 2015].

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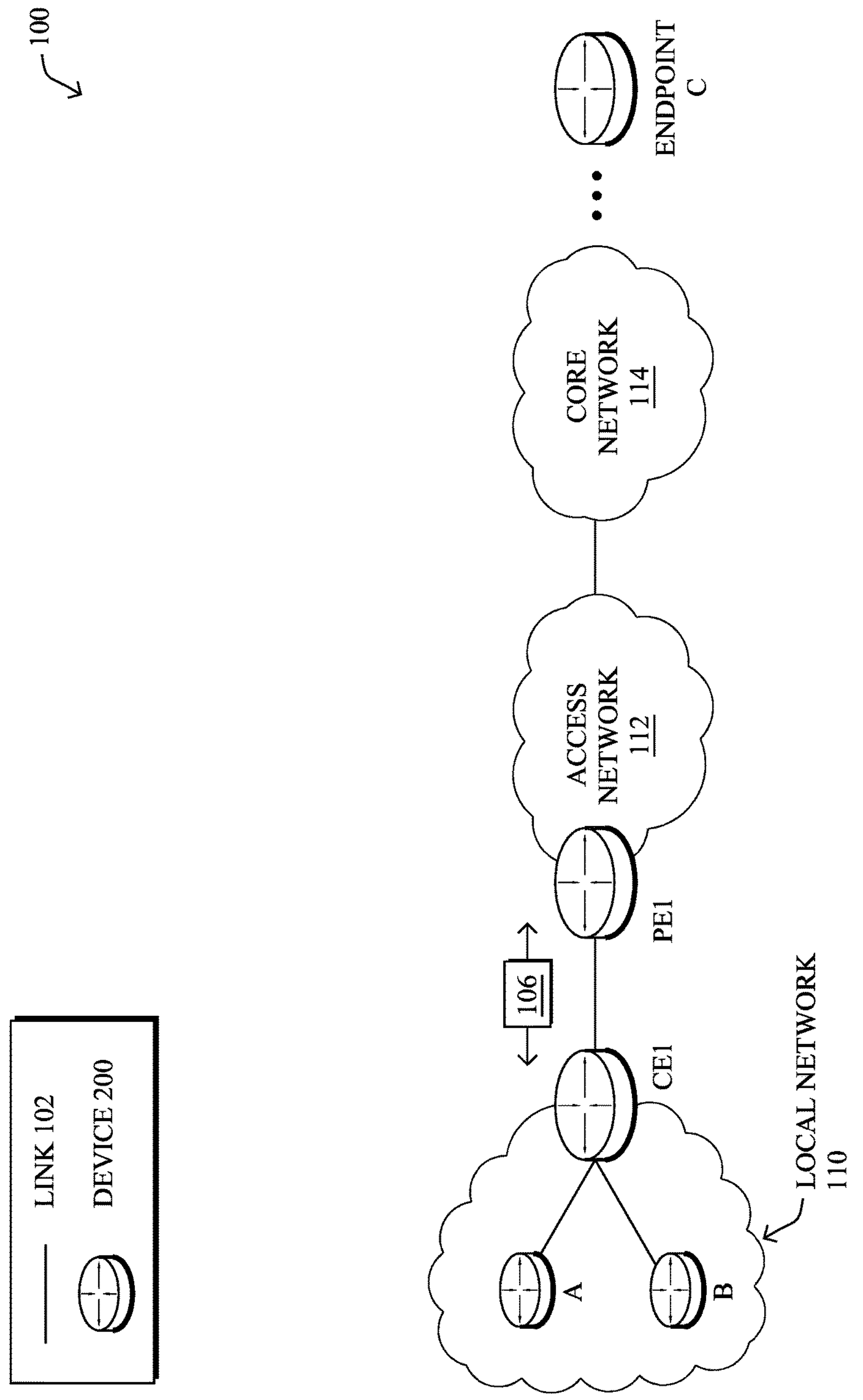
100
LINK 102
DEVICE 200
A
B
CE1
LOCAL NETWORK 110
106
PE1
ACCESS NETWORK 112
CORE NETWORK 114
ENDPOINT C

FIG. 1

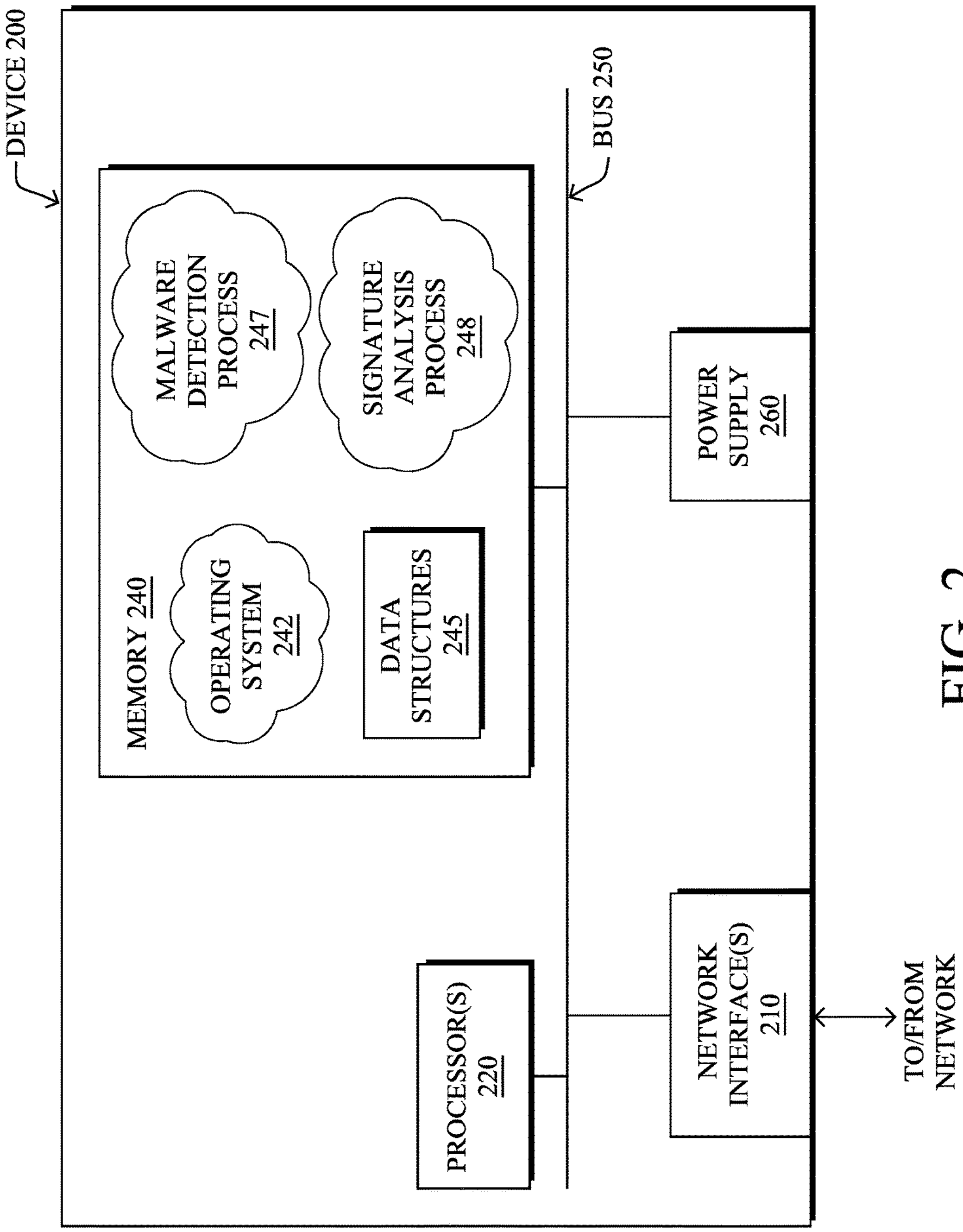
DEVICE 200
BUS 250
MEMORY 240
MALWARE DETECTION PROCESS 247
SIGNATURE ANALYSIS PROCESS 248
OPERATING SYSTEM 242
DATA STRUCTURES 245
POWER SUPPLY 260
PROCESSOR(S) 220
NETWORK INTERFACE(S) 210
TO/FROM NETWORK

FIG. 2

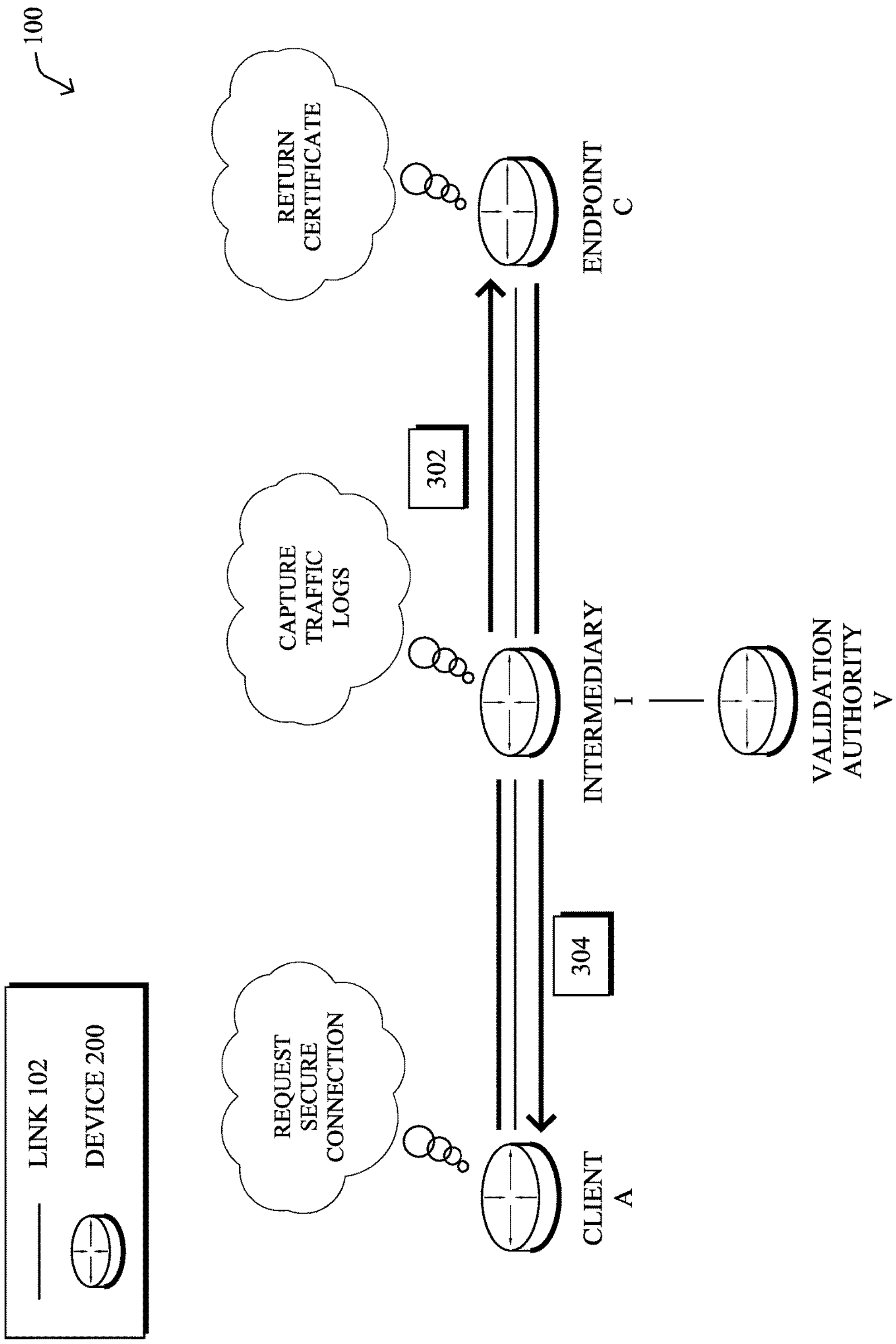
100
LINK 102
DEVICE 200
REQUEST SECURE CONNECTION
CAPTURE TRAFFIC LOGS
RETURN CERTIFICATE
304
302
CLIENT A
INTERMEDIARY I
ENDPOINT C
VALIDATION AUTHORITY V

FIG. 3A

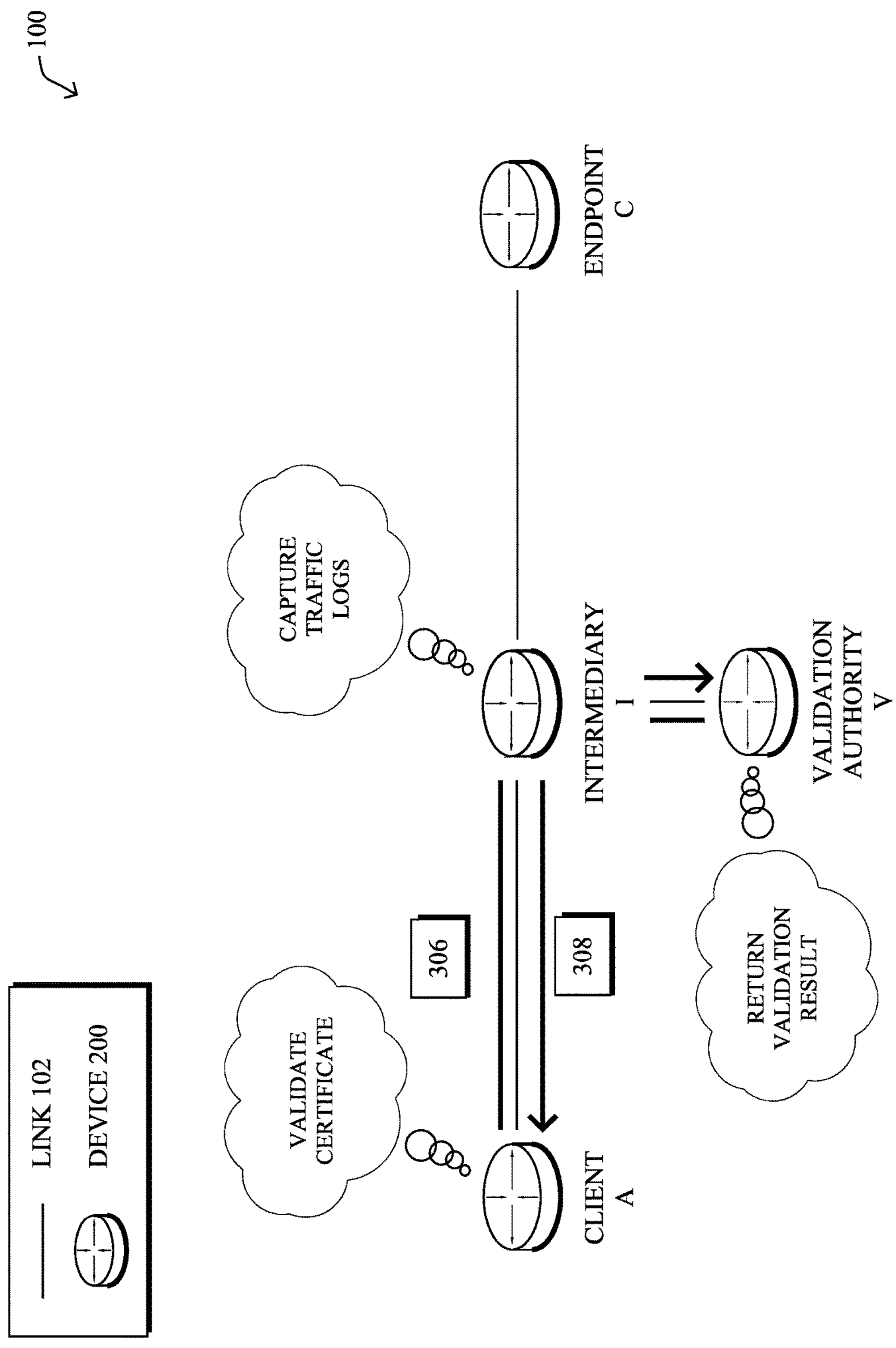
100
LINK 102
DEVICE 200
VALIDATE CERTIFICATE
306
308
CLIENT A
CAPTURE TRAFFIC LOGS
INTERMEDIARY I
ENDPOINT C
RETURN VALIDATION RESULT
VALIDATION AUTHORITY V

FIG. 3B

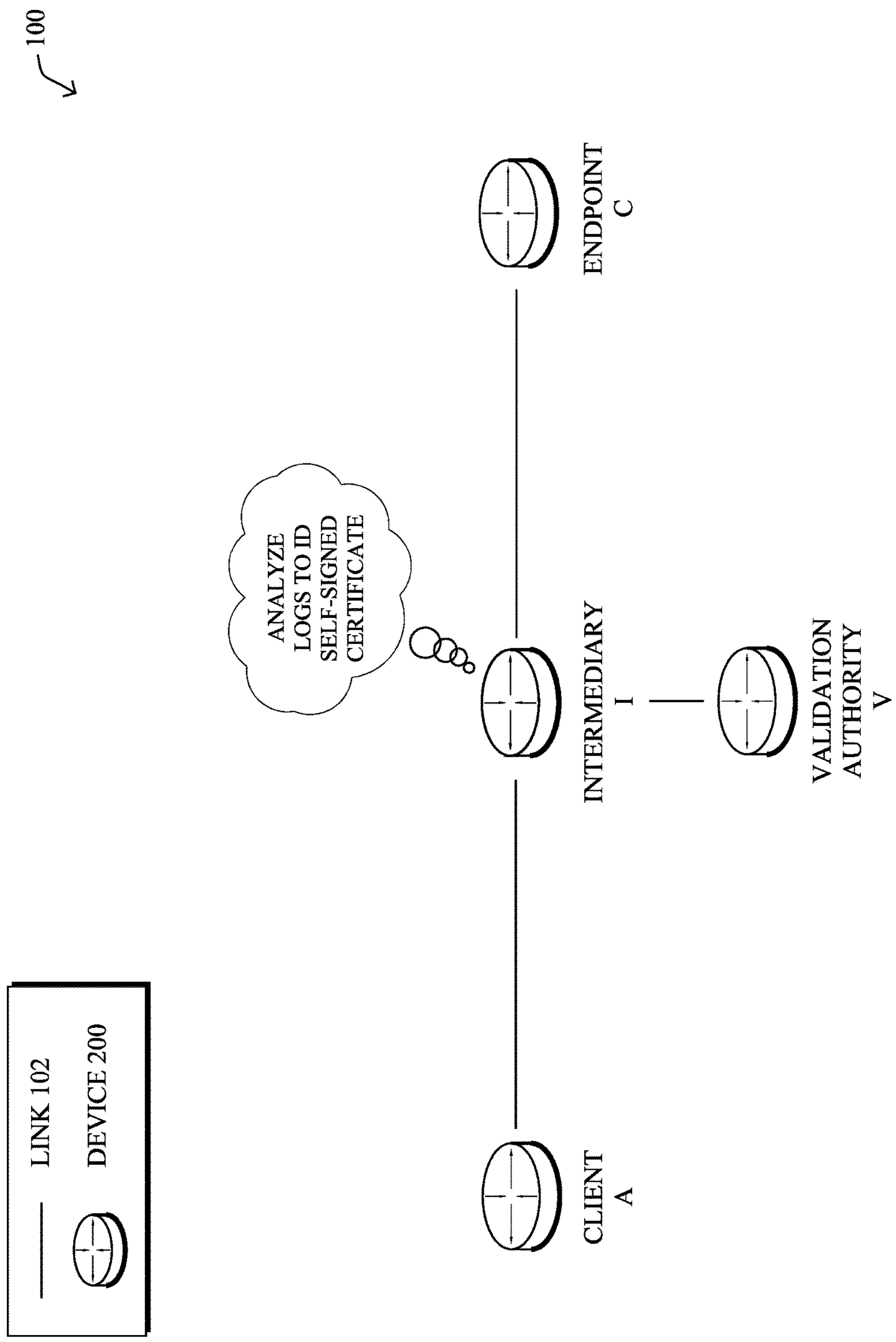
100
LINK 102
DEVICE 200
CLIENT A
INTERMEDIARY I
ENDPOINT C
VALIDATION AUTHORITY V
ANALYZE LOGS TO ID SELF-SIGNED CERTIFICATE

FIG. 3C

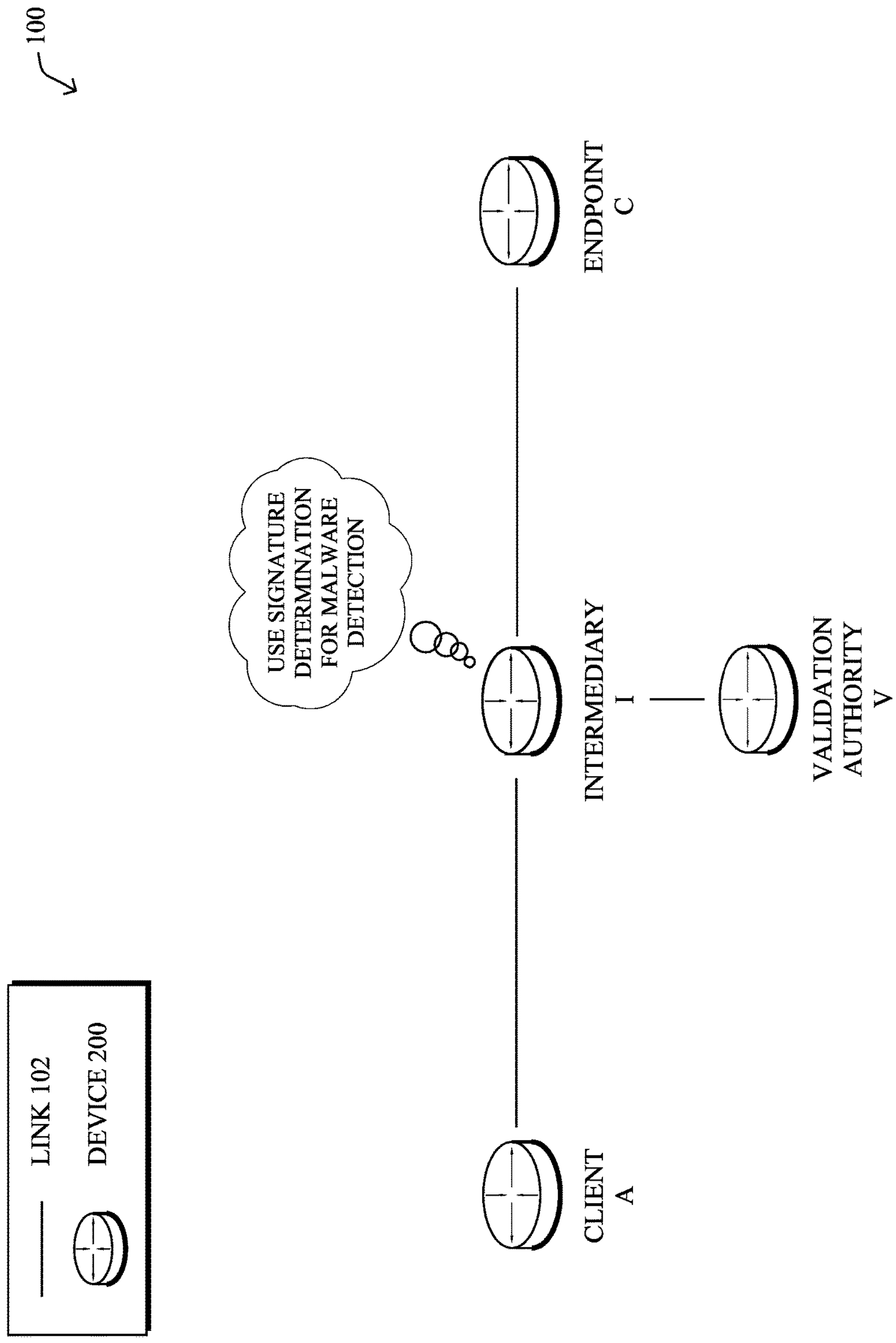
100
LINK 102
DEVICE 200
CLIENT A
INTERMEDIARY I
ENDPOINT C
VALIDATION AUTHORITY V
USE SIGNATURE DETERMINATION FOR MALWARE DETECTION

FIG. 3D

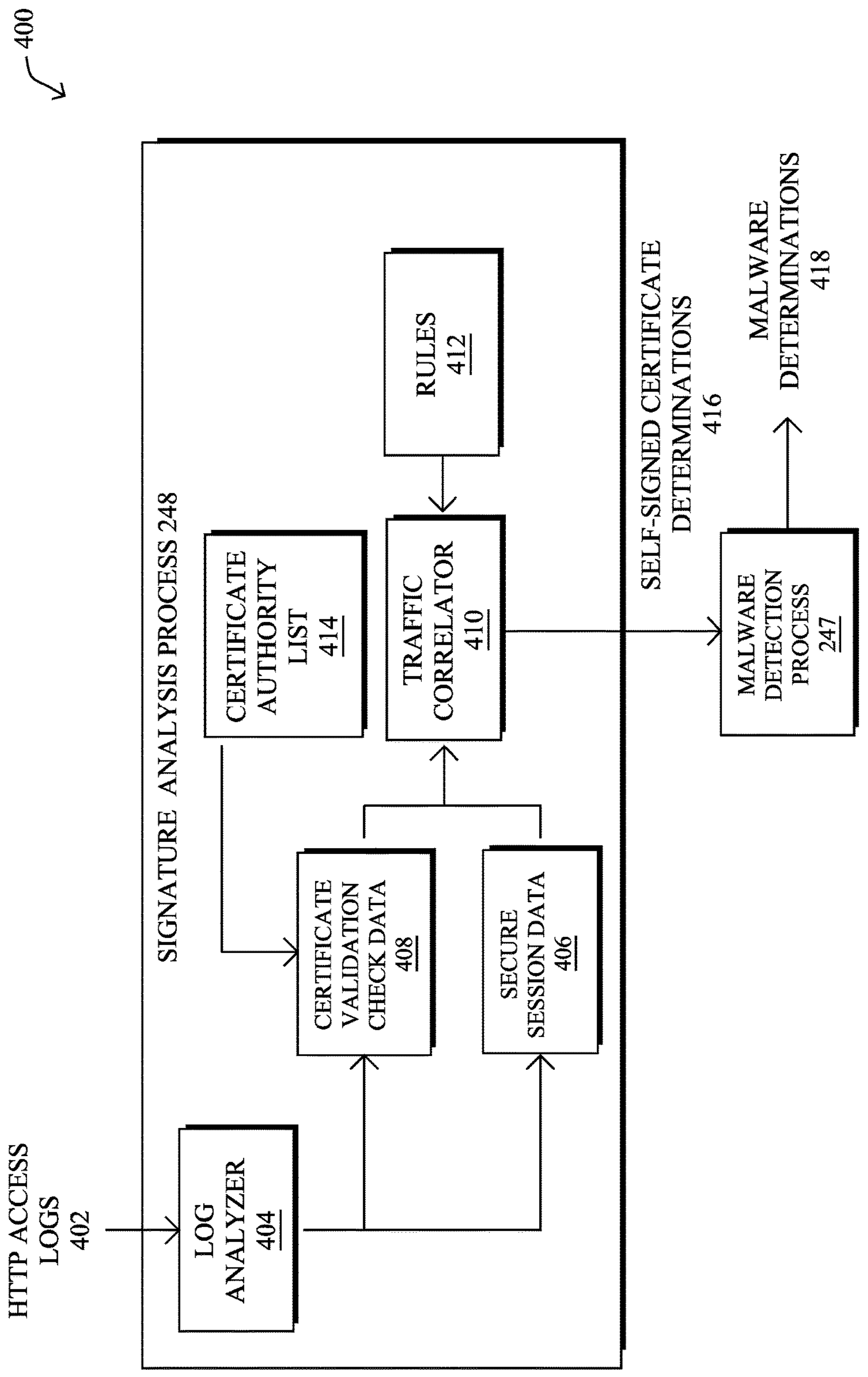
400
HTTP ACCESS LOGS 402
SIGNATURE ANALYSIS PROCESS 248
LOG ANALYZER 404
CERTIFICATE VALIDATION CHECK DATA 408
SECURE SESSION DATA 406
CERTIFICATE AUTHORITY LIST 414
TRAFFIC CORRELATOR 410
RULES 412
SELF-SIGNED CERTIFICATE DETERMINATIONS 416
MALWARE DETECTION PROCESS 247
MALWARE DETERMINATIONS 418

FIG. 4

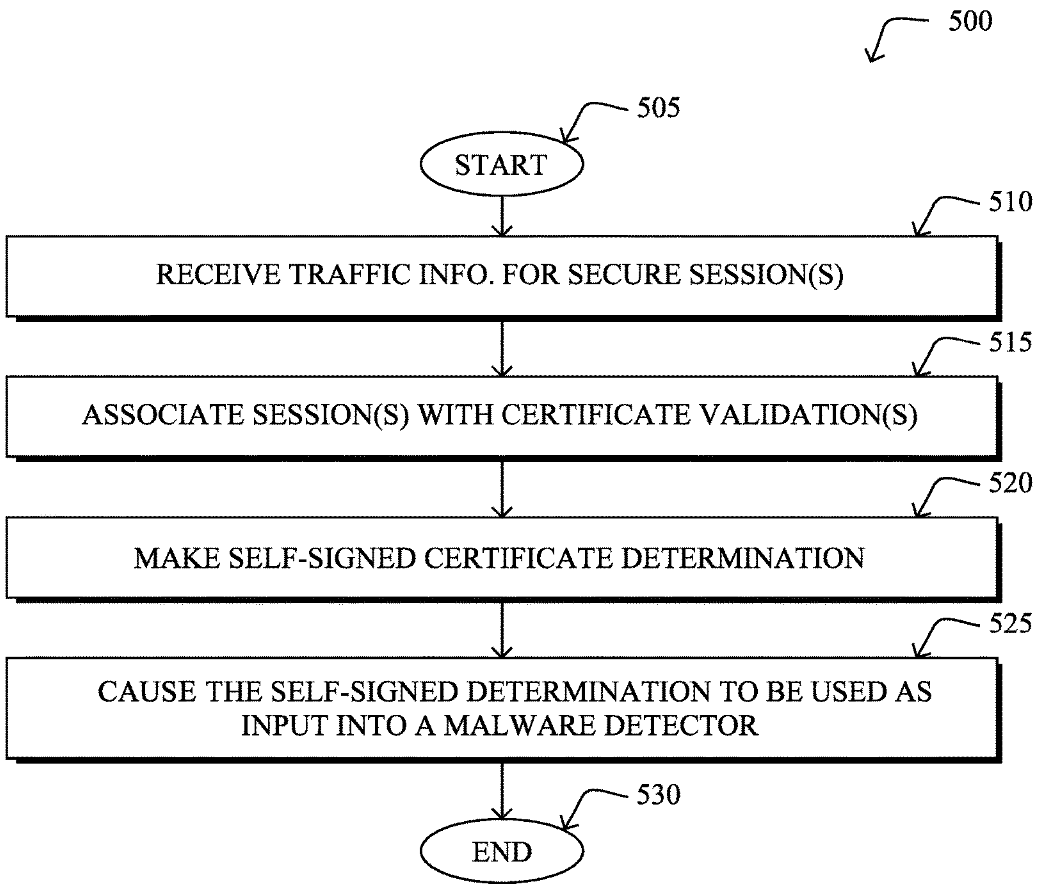
500
505
START
510
RECEIVE TRAFFIC INFO. FOR SECURE SESSION(S)
515
ASSOCIATE SESSION(S) WITH CERTIFICATE VALIDATION(S)
520
MAKE SELF-SIGNED CERTIFICATE DETERMINATION
525
CAUSE THE SELF-SIGNED DETERMINATION TO BE USED AS INPUT INTO A MALWARE DETECTOR
530
END

FIG. 5

IDENTIFYING SELF-SIGNED CERTIFICATES USING HTTP ACCESS LOGS FOR MALWARE DETECTION

TECHNICAL FIELD

The present disclosure relates generally to computer networks, and, more particularly, to identifying self-signed certificates using Hypertext Transfer Protocol (HTTP) access logs for malware detection.

BACKGROUND

Malicious or otherwise undesirable network traffic can take many different forms. For example, some traffic may seek to overwhelm a service by sending a large number of requests to the service. Such attacks are also sometimes known as denial of service (DoS) attacks. Other forms of malicious traffic may seek to exfiltrate sensitive information from a network, such as credit card numbers, trade secrets, and the like. Typically, such traffic is generated by a client that has been infected with malware. Thus, a further type of malicious network traffic includes network traffic that propagates the malware itself. Additionally, some network traffic may simply be deemed inappropriate for a particular network.

Intrusion prevention systems (IPS), next-generation firewalls, and flow monitoring systems generally attempt to detect and block malicious traffic, whenever possible. However, in recent years, the amount of encrypted and evasive network traffic has increased considerably. Notably, with the advent of transport layer security (TLS) and other security mechanisms, many websites are now encrypting even traditional webpage data. This presents certain challenges to traditional security systems as the contents of the traffic may not be available for analysis and pattern matching is generally inapplicable to encrypted traffic.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments herein may be better understood by referring to the following description in conjunction with the accompanying drawings in which like reference numerals indicate identically or functionally similar elements, of which:

FIG. **1** illustrates an example communication network;

FIG. **2** illustrates an example network device/node;

FIGS. **3**A-**3**D illustrate an example of the use of Hypertext Transfer Protocol (HTTP) access logs to identify domains that use self-signed certificates;

FIG. **4** illustrates an example architecture to identify self-signed certificates for malware detection; and

FIG. **5** illustrates an example simplified procedure for identifying self-signed certificates for malware detection.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

According to one or more embodiments of the disclosure, a device in a network receives traffic information regarding one or more secure sessions in the network. The device associates the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information. The device makes a self-signed certificate determination for an endpoint domain of a particular secure session based on whether the particular secure

session is associated with certificate validation check traffic. The device causes the self-signed certificate determination for the endpoint domain to be used as input to a malware detector.

Description

A computer network is a geographically distributed collection of nodes interconnected by communication links and segments for transporting data between end nodes, such as personal computers and workstations. Many types of networks are available, with the types ranging from local area networks (LANs) to wide area networks (WANs). LANs typically connect the nodes over dedicated private communications links located in the same general physical location, such as a building or campus. WANs, on the other hand, typically connect geographically dispersed nodes over long-distance communications links, such as common carrier telephone lines, optical lightpaths, synchronous optical networks (SONET), or synchronous digital hierarchy (SDH) links. The Internet is an example of a WAN that connects disparate networks throughout the world, providing global communication between nodes on various networks. The nodes typically communicate over the network by exchanging discrete frames or packets of data according to predefined protocols, such as the Transmission Control Protocol/Internet Protocol (TCP/IP). In this context, a protocol consists of a set of rules defining how the nodes interact with each other. Computer networks may be further interconnected by an intermediate network node, such as a router, to extend the effective "size" of each network.

FIG. **1** is a schematic block diagram of an example communication network **100** illustratively comprising nodes/devices **200**, such as a plurality of routers/devices interconnected by links and/or networks, as shown. For example, a customer edge (CE) router CE**1** may interconnect nodes A and B on a local network **110** with a provider edge (PE) router PE**1** of an access network **112**. In turn, access network **112** may provide local network **110** with connectivity to a core network **114**, such as the Internet.

The various nodes/devices **200** may exchange data packets **106** (e.g., traffic/messages) via communication network **100** over links **102** using predefined network communication protocols such as the Transmission Control Protocol/Internet Protocol (TCP/IP), User Datagram Protocol (UDP), Asynchronous Transfer Mode (ATM) protocol, Frame Relay protocol, or any other suitable protocol. Those skilled in the art will understand that any number of nodes, devices, links, etc. may be used in the computer network, and that the view shown herein is for simplicity. For example, node A in local network **110** may communicate with an endpoint node/device C (e.g., a remote server, etc.) via communication network **100**.

As would be appreciated, links **102** may include any number of wired and/or wireless connections between devices. For example, node A may communicate wirelessly using a WiFi™ connection, CE**1** and PE**1** may communicate wirelessly using a cellular connection or via a hardwired connection (e.g., DSL, etc.), etc. In addition, while certain devices are depicted in FIG. **1**, the view shown is a simplified view of communication network **100**. In other words, communication network **100** may also include any number of intermediary networking devices such as, but not limited to, routers, switches, firewalls, etc., that are not shown.

In various embodiments, nodes/devices **200** may employ a secure communication mechanism, to encrypt and decrypt data packets **106**. For example, nodes/devices **200** shown may use a Transport Layer Security (TLS) mechanism, such as the HTTP Secure (HTTPS) protocol, to encrypt and decrypt data packets **106**.

FIG. **2** is a schematic block diagram of an example node/device **200** that may be used with one or more embodiments described herein, e.g., as any of the computing devices shown in FIG. **1**, any other computing device that supports the operations of network **100** (e.g., switches, etc.), or any of the other devices referenced below. The device **200** may also be any other suitable type of device depending upon the type of network architecture in place. As shown, device **200** comprises one or more network interface(s) **210**, one or more processor(s) **220**, and a memory **240** interconnected by a system bus **250** and powered by a power supply **260**.

The network interface(s) **210** include the mechanical, electrical, and signaling circuitry for communicating data over physical links coupled to the network **100**. The network interfaces may be configured to transmit and/or receive data using a variety of different communication protocols. Notably, a physical network interface **210** may also be used to implement one or more virtual network interfaces, such as for virtual private network (VPN) access, known to those skilled in the art.

The memory **240** comprises a plurality of storage locations that are addressable by the processor(s) **220** and the network interface(s) **210** for storing software programs and data structures associated with the embodiments described herein. The processor **220** may comprise necessary elements or logic adapted to execute the software programs and manipulate the data structures **245**. An operating system **242** (e.g., the Internetworking Operating System, or IOS®, of Cisco Systems, Inc., another operating system, etc.), portions of which are typically resident in memory **240** and executed by the processor(s), functionally organizes the node by, inter alia, invoking network operations in support of software processors and/or services executing on the device. These software processors and/or services may comprise a malware detection process **247** and/or a signature analysis process **248**, as described herein.

It will be apparent to those skilled in the art that other processor and memory types, including various computer-readable media, may be used to store and execute program instructions pertaining to the techniques described herein. Also, while the description illustrates various processes, it is expressly contemplated that various processes may be embodied as modules configured to operate in accordance with the techniques herein (e.g., according to the functionality of a similar process). Further, while processes may be shown and/or described separately, those skilled in the art will appreciate that processes may be routines or modules within other processes.

In general, malware detection process **247** may employ machine learning and/or detection rules, to detect the presence of malware in the network. For example, malware detection process **247** may classify traffic in the network (and its corresponding application or client node) as being either benign or malware-related. In one embodiment, malware detection process **247** may assess captured traffic data to determine whether a given traffic flow or set of flows are caused by malware in the network, such as a particular family of malware applications. Example forms of traffic that can be caused by malware may include, but are not limited to, traffic flows reporting exfiltrated data to a remote entity, spyware or ransomware-related flows, command and control (C&C) traffic that oversees the operation of the deployed malware, traffic that is part of a network attack, such as a zero day attack or denial of service (DoS) attack, combinations thereof, or the like. In further embodiments, malware detection process **247** may classify the gathered traffic data to detect other anomalous behaviors (e.g., malfunctioning devices, misconfigured devices, etc.), traffic pattern changes (e.g., a group of hosts begin sending significantly more or less traffic), or the like.

Malware detection process **247** may employ any number of machine learning techniques to assess the gathered traffic data. In general, machine learning is concerned with the design and the development of techniques that receive empirical data as input (e.g., traffic data regarding traffic in the network) and recognize complex patterns in the input data. For example, some machine learning techniques use an underlying model M, whose parameters are optimized for minimizing the cost function associated to M, given the input data. For instance, in the context of classification, the model M may be a straight line that separates the data into two classes (e.g., labels) such that M=a*x+b*y+c and the cost function is a function of the number of misclassified points. The learning process then operates by adjusting the parameters a,b,c such that the number of misclassified points is minimal. After this optimization/learning phase, detection process **247** can use the model M to classify new data points, such as information regarding new traffic flows in the network. Often, M is a statistical model, and the cost function is inversely proportional to the likelihood of M, given the input data.

In various embodiments, malware detection process **247** may employ one or more supervised, unsupervised, or semi-supervised machine learning models. Generally, supervised learning entails the use of a training set of data, as noted above, that is used to train the model to apply labels to the input data. For example, the training data may include sample traffic data that is “normal,” or “malware-generated.” On the other end of the spectrum are unsupervised techniques that do not require a training set of labels. Notably, while a supervised learning model may look for previously seen attack patterns that have been labeled as such, an unsupervised model may instead look to whether there are sudden changes in the behavior of the network traffic. Semi-supervised learning models take a middle ground approach that uses a greatly reduced set of labeled training data.

Example machine learning techniques that malware detection process **247** can employ may include, but are not limited to, nearest neighbor (NN) techniques (e.g., k-NN models, replicator NN models, etc.), statistical techniques (e.g., Bayesian networks, etc.), clustering techniques (e.g., k-means, mean-shift, etc.), neural networks (e.g., reservoir networks, artificial neural networks, autoencoders, etc.), support vector machines (SVMs), logistic or other regression, Markov models or chains, principal component analysis (PCA) (e.g., for linear models), multi-layer perceptron (MLP) ANNs (e.g., for non-linear models), replicating reservoir networks (e.g., for non-linear models, typically for time series), random forest classification, or the like.

The performance of a machine learning model can be evaluated in a number of ways based on the number of true positives, false positives, true negatives, and/or false negatives of the model. For example, the false positives of the model may refer to the number of traffic flows that are incorrectly classified as malware-generated, anomalous, etc. Conversely, the false negatives of the model may refer to the number of traffic flows that the model incorrectly classifies as normal, when actually malware-generated, anomalous, etc. True negatives and positives may refer to the number of traffic flows that the model correctly classifies as normal or malware-generated, etc., respectively. Related to these measurements are the concepts of recall and precision. Generally, recall refers to the ratio of true positives to the sum of true positives and false negatives, which quantifies the sensitivity of the model. Similarly, precision refers to the ratio of true positives the sum of true and false positives.

In some cases, malware detection process **247** may assess the captured traffic data on a per-flow basis. In other embodiments, malware detection process **247** may assess traffic data for a plurality of traffic flows based on any number of different conditions. For example, traffic flows may be grouped based on their sources, destinations, temporal characteristics (e.g., flows that occur around the same time, etc.), combinations thereof, or based on any other set of flow characteristics.

As noted above, botnets represent a particular security concern for network administrators. Once a client device has been infected with malware for the botnet, it may communicate with a command and control (C&C) server which sends control commands to the infected device. For example, a C&C server may issue commands to many malware-infected devices, to instruct the infected devices to launch a coordinated DDoS attack on a particular target.

Encryption is increasingly being used to conceal malware-related traffic. For example, a large number of malware reports indicate that ongoing advanced persistent threat (APT) campaigns use Transport Layer Security (TLS) to encrypt network communications between an infected client device and the C&C servers. From analysis of encrypted traffic that is malware-related, the inventors herein have observed that the security certificates used for malware-related traffic are also typically self-signed. This is in contrast to security certificates that are signed by a trusted certification authority.

Two reasons may exist for malicious traffic using self-signed certificates. First, self-signed certificates are free, whereas certification authority-signed certificates are not. Second, to obtain a certificate signed by a certification authority, the attacker/malicious entity would need to provide an identity to the certification authority for verification. Naturally, an attacker/malicious entity would want to remain as anonymous as possible, to avoid criminal penalties.

With respect to self-signed certificates, most web browsers now display a security alert since self-signed certificates are not verified by a trusted CA. Often, the alert advises the user to abort the webpage for security reasons (e.g., by displaying a message that the page is untrusted). Consequently, Internet users tend to avoid browsing sites that use self-signed certificates. In contrast, however, non-browser applications and/or malware may not be as regulating and continue to establish connections with servers that use self-signed certificates. Accordingly, the use of self-signed certificates by websites and domains may be an indicator of malicious activity.

Identifying Self-Signed Certificates using HTTP Access Logs for Malware Detection

The techniques herein allow for the identification of domains that use self-signed certificates based only on the HTTP access logs regarding the secure session. In some aspects, the techniques herein may analyze certificate validation checks in the access logs, to identify whether the domain of the secure session issued a self-signed certificate or not. More specifically, if the receiving client of a certificate for a secure session does not perform a subsequent validation check (e.g., by issuing a validation request to a validation authority), this is a strong indication that the

certificate was self-signed by the corresponding domain. By modeling the HTTP logs surrounding the HTTP Secure (HTTPS) requests to each domain, the techniques are able to distinguish self-signed certificates with high precision. In further aspects, the self-signature decision may be used as input to a malware detection process, e.g., as one of the factors assessed by the detector.

Specifically, according to one or more embodiments of the disclosure as described in detail below, a device in a network receives traffic information regarding one or more secure sessions in the network. The device associates the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information. The device makes a self-signed certificate determination for an endpoint domain of a particular secure session based on whether the particular secure session is associated with certificate validation check traffic. The device causes the self-signed certificate determination for the endpoint domain to be used as input to a malware detector.

Illustratively, the techniques described herein may be performed by hardware, software, and/or firmware, such as in accordance with the signature analysis process **248**, which may include computer executable instructions executed by the processor **220** (or independent processor of interfaces **210**) to perform functions relating to the techniques described herein, e.g., in conjunction with malware detection process **247**.

Operationally, FIGS. **3**A-**3**D illustrate an example of the use of HTTP access logs to identify domains that use self-signed certificates, according to various embodiments. As shown in FIG. **3**A, network **100** may include an endpoint client node/device A, an endpoint node/device C (e.g., a server), and an intermediary node/device I located therebetween. For example, the intermediary device I may be a router, switch, firewall, intrusion detection system (IDS), intrusion prevention system (IPS), proxy server, or other networking device through which traffic exchanged between nodes/device A and C may flow.

A simplified example of the establishment of a secure session between devices A and C is also shown in FIG. **3**A. First, client A may send a request **302** to endpoint C to establish a secure session/connection. As would be appreciated, client A may perform a domain name system (DNS) lookup for the domain of endpoint C, prior to sending request **302**, if the address of endpoint C is not already known. In other words, client A may initiate handshaking with endpoint C during which client A and endpoint C may exchange the information needed to securely communicate with one another. For example, request **302** may be a 'hello' message that indicates the ciphersuites supported by client A, a random number, or other such handshaking information.

In response to receiving request **302**, endpoint C may send a response **304** to client A that includes its security certificate. As noted previously, two possibilities exist with respect to the signature on the certificate. In some cases, the security certificate may be signed by a certification authority. Such may be the case if the entity associated with the domain of endpoint C first proved his or her identity to the certification authority and paid a fee. The other possibility, as noted previously, is that the security certificate sent by endpoint C to client A is self-signed. In such a case, the certificate may instead be signed by the entity associated with endpoint C to certify its own identity (e.g., as opposed to certification from a third party certification authority). Example security certificates may include, but are not limited to, Secure Socket

Layer (SSL) certificates, X.509 certificates, public key infrastructure (PKI) certificates, or the like.

Intermediary device I may capture traffic information regarding the exchange between client A and endpoint C. For example, intermediary device I may capture information regarding the address of client A, the address of endpoint C, the domain of endpoint C, the ciphersuite in use, timing information (e.g., when client A sent request **302**, etc.), or any other information available from the data exchange between client A and endpoint C.

As shown in FIG. **3**B, after receiving the certificate from endpoint C, client A may attempt to validate the certificate using a validation authority, if the certificate was signed by a certification authority. Notably, if a domain uses such an SSL certificate, a browser on the client will then typically verify that the signature from the certification authority is still valid and not revoked. For example, client A may send a certificate validation request **306** to validation authority device V via intermediary device I. In some cases, the validation authority may be issuing certification authority itself. In other cases, however, the validation authority may be kept separate so that previously issued certificates can still be validated, even if the certification authority is unavailable.

Validation request **306** may use any of several different HTTP protocols to perform the certificate validation (e.g., PKI, etc.). One such protocol is the Online Certificate Status Protocol (OCSP) which is used to check the revocation status of X.509 certificates. In such a case, the validation authority VA may be viewed as an OCSP responder. Another validation approach would be to use Certificate Revocation List (CRL) downloads. In general, CRLs are lists of certificates that have been revoked by their issuing certification authorities. OCSP and CRL downloads work in a similar manner, but with OCSP responses including less overall information than that of a CRL download. As would be appreciated, validation request **306** may take the form of any other validation protocol/mechanism, as desired.

In response to receiving request **306**, the validation authority V may return a validation result **308** to client A. In turn, client A is now able to determine whether the certification authority-signed certificate sent by endpoint C is indeed valid. If so, client A may continue the handshaking process and establish a secure session with endpoint C (e.g., by exchanging cryptographic data with endpoint C, etc.).

Similar to the initial request/response between client A and endpoint C, intermediary device I may also capture HTTP information regarding the validation exchange between client A and validation authority V. For example, intermediary device I may capture address information for client A, address information for validation authority V, timing information (e.g., when client A sent validation request **306**, etc.), information regarding the certificate validation protocol/mechanism in use, or any other information regarding the validation exchange. Such validation requests can be thus be recognized in the HTTP access log data (e.g., using their signatures—typical patterns in uniform resource locators (URLs) such as file name extensions or MIME types, etc.). In this way, intermediary device I may capture HTTP traffic logs for both the initial client A-endpoint C exchange, as well as the subsequent validation exchange between client A and validation authority V.

As shown in FIG. **3**C, intermediary device I may analyze its HTTP access log data, to determine whether the certificate used by the domain of endpoint C was self-signed. Notably, if the certificate used by endpoint C was self-signed, it is not expected for there to be associated certificate validation check traffic from client A. By analyzing the HTTP logs in this manner, intermediary device I can make a determination as to whether or not the certificate used by endpoint C was self-signed. In other embodiments, intermediary device I may provide the captured traffic information to another device that performs this analysis. For example, intermediary device I (or a plurality of such intermediaries) may provide HTTP access logs to another analysis device for purposes of identifying self-signed certificates.

As shown in FIG. **3**D, based on the self-signed certificate determination for the certificate from endpoint C, intermediary device I (or another device) may use this determination as a factor when detecting the presence of malware in the network. Other factors that the malware detector may consider could include, but are not limited to, metrics regarding the traffic itself (e.g., packet length and time information, associated applications, etc.), DNS information regarding the domain of endpoint C (e.g., whether the domain was generated by a domain generation algorithm (DGA), etc.), header information from the exchange between client A and endpoint C, and the like.

FIG. **4** illustrates an example architecture **400** to identify self-signed certificates for malware detection, according to various embodiments. As shown, signature analysis process **248** may include a number of sub-processes and access storage locations, either on a local device (e.g., device **200**) or across a plurality of devices that implement signature analysis process **248**.

In some embodiments, signature analysis process **248** may include a log analyzer **404** that receives HTTP access logs **402**. Such logs may be captured by one or more intermediary devices between any number clients and endpoints/domains. More specifically, access logs **402** may comprise traffic information regarding one or more secure sessions in the network (e.g., handshake traffic, certificate validation traffic, etc.).

Log analyzer **404** may be configured to parse out secure session data **406** and certificate validation check data **408** from HTTP access logs **402**. Secure session data **406** may include, for example, data indicative of the clients and domains involved in secure sessions in the network, timing information for the secure sessions (e.g., when a secure sessions was requested or established, etc.), or any other information that can be captured from the HTTP traffic associated with a secure session.

Likewise, certificate validation check data **408** may include any information regarding the HTTP-based certificate validation check traffic. For example, certificate validation check data **408** may include information indicative of the clients that issued the validation check requests, the validation authorities queried, timing information regarding the validation check traffic (e.g., when a client sent a validation request, etc.), or any other information available from HTTP access logs **402** regarding certificate validation request. Log analyzer **404** may, for example, identify traffic information from HTTP access logs **402** that conform to a known certificate validation protocol/mechanism (e.g., OCSP, CRL downloads, etc.), by comparing the validation authorities to a known list of common certification or validation authorities (e.g., certificate authority list **414**), or the like.

According to various embodiments, signature analysis process **248** may include a traffic correlator **410** configured to correlate secure session data **406** with certificate validation check data **408**. Based on the correlations, traffic correlator **410** may generate and provide self-signed certificate determinations **416** to malware detection process **247** which may be executed on the same local device or another device in the network.

In some embodiments, traffic correlator **410** may employ any number of heuristic rules **412**, to determine whether a particular domain likely issued a self-signed certificate. For example, rules **412** may be heuristics without 100% precision to increase their recall because, as described below, traffic correlator **410** may base a determination **416** on a plurality of visits to the corresponding domain, to suppress possible errors. Generally, traffic correlator **410** may determine whether or not a given client that requested a secure session subsequently performed a validation of the certificate (e.g., within a predefined timeframe of one another, etc.), based on data **406**-**408**.

In some cases, a certificate check might not be always present in the logs even if the domain is using a properly signed certificate. For example, if the information about the certificate has already been cached by the browser application of the client, the browser is unlikely to generate certificate validation check traffic. Thus, in some embodiments, traffic correlator **410** may combine and assess traffic information from visits to the domain under scrutiny by a plurality of clients and over a longer period of time, to determine whether the domain uses a self-signed certificate. For example, if there is at least one client that generated certificate validation check traffic that is associated with a secure session request from that client and involving the domain, traffic correlator **410** may determine that the domain issued a certificate signed by a certification authority. Otherwise, traffic correlator **410** may determine that the domain issued a self-signed certificate (e.g., if none of the clients involved in secure sessions with the domain sent certificate validation requests).

Malware detection process **247** may use the self-signed certificate determinations **416** as input, to generate malware determinations **418**. In turn, malware determinations **418** can be used by the malware detector to initiate one or more mitigation actions in the network. For example, if a particular domain is flagged as malware-related, the malware detector may block traffic to this domain. Similarly, if a particular client is found to have contacted one or more malware-related domains, the malware detector may send an alert (e.g., to a network administrator) to initiate corrective actions.

By way of non-limiting example of the operation of architecture **400**, consider the case of a client device visiting twitter.com. Such a visit is typically accompanied by a certificate check to verify the certificate at the issuer. Thus, the HTTP access logs may capture the following URLs:

https://twitter.com

http://ocsp2.globalsign.com/gsalphasha2g2/MFMwUTBPMEOwSzAJBgUrDgMC
GgUABBSE1Wv4CYvTB7dm2OHrrWWWqmtnYQQU9c3VPAhQ%2BWpPOreX2laD5mn
SaPcCEhEhQy17zc7ooUokaeXd8t99CQ%3D%3D

From the HTTP access logs **402**, log analyzer **404** may parse out the secure session data **406** regarding the traffic to the first URL (e.g., the address of the client that requested the URL, timing information regarding the request, etc.) and the certificate validation check data **408** regarding the traffic to the second URL. By assessing this data, traffic correlator **410** may determine that the same client sent traffic to both URLs within a predefined timespan of one another, thereby indicating that the client performed a validation check on the certificate issued by the first URL. Based on this, traffic correlator may determine that the domain of the first URL used a certificate signed by a certification authority.

FIG. **5** illustrates an example simplified procedure for identifying self-signed certificates for malware detection, in accordance with the teachings herein. For example, a non-generic, specifically configured device (e.g., device **200**) may perform procedure **400** by executing stored instructions (e.g., process **247** and/or process **248**). The procedure **500** may start at step **505**, and continues to step **510**, where, as described in greater detail above, the device may receive traffic information regarding one or more secure sessions in the network. For example, the device may receive captured HTTP access log data regarding traffic flows before, during, and/or after a secure session is established between a client in the network and an endpoint domain.

At step **515**, as detailed above, the device may associate the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information. For example, the device may match the client address that requested a secure session with a client address from the certificate validation check traffic (e.g., the same client both requested a secure session and performed a certificate validation check). In some embodiments, the device may make such associations based on the timing of the secure session request/handshake and the certificate validation check traffic (e.g., if the same client sent both types of traffic within a predefined timespan).

At step **520**, the device may make a self-signed certificate determination for an endpoint domain of a particular secure session based on whether the particular secure session is associated with certificate validation check traffic, as described in greater detail above. Notably, if the client involved in the particular secure session also generated certificate validation check traffic associated with the secure session, the device may determine that the certificate used by the domain was signed by a certification authority. Conversely, if the device finds no such association between the session and a validation check by the client, the device may determine that the endpoint domain of the secure session used a self-signed certificate. In further embodiments, the device may base self-signed certificate determination for the domain on a plurality of secure sessions. For example, if none of the secure sessions with the domain are associated with certificate validation check traffic (e.g., across multiple clients, etc.), the device may determine that the domain uses self-signed certificates.

At step **525**, as detailed above, the device may cause the self-signed certificate determination to be used as input to a malware detector. In some cases, the malware detector may be executed by the device itself. In other cases, the device may provide the self-signed certificate determination to another device in the network that acts as a malware detector. Such a malware detector may use rules, machine learning, or any other malware analysis technique to determine whether the corresponding domain is associated with malware. Procedure **500** then ends at step **530**.

It should be noted that while certain steps within procedure **500** may be optional as described above, the steps shown in FIG. **5** are merely examples for illustration, and certain other steps may be included or excluded as desired. Further, while a particular order of the steps is shown, this ordering is merely illustrative, and any suitable arrangement of the steps may be utilized without departing from the scope of the embodiments herein.

The techniques described herein, therefore, allow for the detection of self-signed certificates based solely on HTTP access log data. In other words, the techniques herein do not require content inspection of the certificate itself and can be used in real-time applications. Further, the techniques herein do not require the malware detection system to download the certificate itself, to determine whether the corresponding domain uses self-signed certificates.

While there have been shown and described illustrative embodiments that provide for the identification of self-signed certificates, it is to be understood that various other adaptations and modifications may be made within the spirit and scope of the embodiments herein. For example, while certain embodiments are described herein with respect to using certain models for purposes of malware detection, the models are not limited as such and may be used for other functions, in other embodiments. In addition, while certain protocols are shown, other suitable protocols may be used, accordingly.

The foregoing description has been directed to specific embodiments. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their advantages. For instance, it is expressly contemplated that the components and/or elements described herein can be implemented as software being stored on a tangible (non-transitory) computer-readable medium (e.g., disks/CDs/RAM/EEPROM/etc.) having program instructions executing on a computer, hardware, firmware, or a combination thereof. Accordingly this description is to be taken only by way of example and not to otherwise limit the scope of the embodiments herein. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the embodiments herein.

What is claimed is:

1. A method, comprising:

receiving, at a device in a network, traffic information regarding one or more secure sessions in the network;

associating, by the device, the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information;

determining, by the device, that an endpoint domain used a self-signed certificate in a particular secure session of the one or more secure sessions based on the particular secure session not being associated with the certificate validation check traffic;

making, by the device, a self-signed certificate determination for the endpoint domain of the particular secure session based on the determination that the endpoint domain used the self-signed certificate in the particular secure session; and

causing, by the device, the self-signed certificate determination for the endpoint domain to be used as input to a malware detector.

2. The method as in claim **1**, wherein the malware detector causes the performance of a mitigation action in the network when the malware detector detects malware.

3. The method as in claim **1**, wherein the malware detector is configured to treat a self-signed certificate for a domain as an indication of the presence of malware in the network.

4. The method as in claim **1**, wherein the traffic information regarding the one or more secure sessions comprises Hypertext Transfer Protocol (HTTP) access logs regarding HTTP traffic associated with the one or more secure sessions.

5. The method as in claim **1**, wherein associating the one or more secure sessions with corresponding certificate validation check traffic comprises:

matching, by the device, client addresses of the one or more secure sessions with client addresses of the certificate validation check traffic.

6. The method as in claim **1**, wherein the certificate validation check traffic comprises a certificate revocation list (CRL) download or an Online Certificate Status Protocol (OCSP) check.

7. The method as in claim **1**, wherein the self-signed certificate determination for the endpoint domain is based on whether any of the one or more secure sessions involving the endpoint domain are associated with certificate validation check traffic.

8. The method as in claim **1**, wherein receiving the traffic information regarding the one or more secure sessions in the network comprises:

capturing, by the device, the traffic information regarding the one or more secure sessions in the network.

9. An apparatus, comprising:

one or more network interfaces to communicate with a network;

a processor coupled to the network interfaces and configured to execute one or more processes; and

a memory configured to store a process executable by the processor, the process when executed operable to:

receive traffic information regarding one or more secure sessions in the network;

associate the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information;

determine that an endpoint domain used a self-signed certificate in a particular secure session of the one or more secure sessions based on the particular secure session not being associated with the certificate validation check traffic;

make a self-signed certificate determination for the endpoint domain of the particular secure session based on the determination that the endpoint domain used the self-signed certificate in the particular secure session; and

cause the self-signed certificate determination for the endpoint domain to be used as input to a malware detector.

10. The apparatus as in claim **9**, wherein the malware detector causes the performance of a mitigation action in the network when the malware detector detects malware.

11. The apparatus as in claim **9**, wherein the malware detector is configured to treat a self-signed certificate for a domain as an indication of the presence of malware in the network.

12. The apparatus as in claim **9**, wherein the traffic information regarding the one or more secure sessions comprises Hypertext Transfer Protocol (HTTP) access logs regarding HTTP traffic associated with the one or more secure sessions.

13. The apparatus as in claim **9**, wherein the apparatus associates the one or more secure sessions with corresponding certificate validation check traffic by:

matching client addresses of the one or more secure sessions with client addresses of the certificate validation check traffic.

14. The apparatus as in claim **9**, wherein the certificate validation check traffic comprises a certificate revocation list (CRL) download or an Online Certificate Status Protocol (OCSP) check.

15. The apparatus as in claim **9**, wherein the self-signed certificate determination for the endpoint domain is based on whether any of the one or more secure sessions involving the endpoint domain are associated with certificate validation check traffic.

16. The apparatus as in claim **9**, wherein the apparatus receives the traffic information regarding the one or more secure sessions in the network by:

capturing the traffic information regarding the one or more secure sessions in the network.

17. A tangible, non-transitory, computer-readable medium storing program instructions that cause a device in a network to execute a process comprising:

receiving, at the device, traffic information regarding one or more secure sessions in the network;

associating, by the device, the one or more secure sessions with corresponding certificate validation check traffic indicated by the received traffic information;

determining, by the device, that an endpoint domain used a self-signed certificate in a particular secure session of the one or more secure sessions based on the particular secure session not being associated with the certificate validation check traffic;

making, by the device, a self-signed certificate determination for the endpoint domain of the particular secure session based on the determination that the endpoint domain used the self-signed certificate in the particular secure session; and

causing, by the device, the self-signed certificate determination for the endpoint domain to be used as input to a malware detector.

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